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Reactor Analysis Division

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1.0 INTRODUCTION

The French and British nuclear programs have prepared a series of natural uranium oxide fuel samples spiked with small amounts of the individual fission products which make up a large fraction of the total neutron absorption by fission products in spent nuclear fuel. Both programs have utilized these samples in experimental reactors and have inferred the worth of the individual fission products. These results have been used to validate the cross sections used in criticality safety calculations. These measurements constitute a major element in support of spent fuel burnup credit in these countries.

The French Atomic Energy Commission (CEA) has informally offered to make these samples available at no cost to the US program, for measurements to be conducted in the SHEBA facility at LANL. As a condition of the sample loan, the French have indicated four things:

(1) Demonstrate a *priori* that the experiments are going to have technical merit;

(2) Access to all results;

(3) U.S. pays the cost of transportation (e.g., ~$20k round-trip);

(4) Return of the samples on a pre-determined date.

LANL has prepared a white paper to support these experiments.[1] Moreover, LANL has demonstrated that the neutron spectrum in the SHEBA reactor closely matches the neutron spectrum for PWR bundles in a shipping cask.[2] ANL has performed a pre-analysis of the SHEBA experiments to demonstrate their validity and usefulness to the US program.

2.0 BRIEF DESCRIPTION OF THE SHEBA MEASUREMENTS

The SHEBA critical assembly machine is a cylindrical tank containing Uranium Fluoride solution fuel. The CERES samples will be located within a steel well in the tank to isolate them from the fuel solution. Figure 1 shows the location of the samples in the SHEBA assembly. The

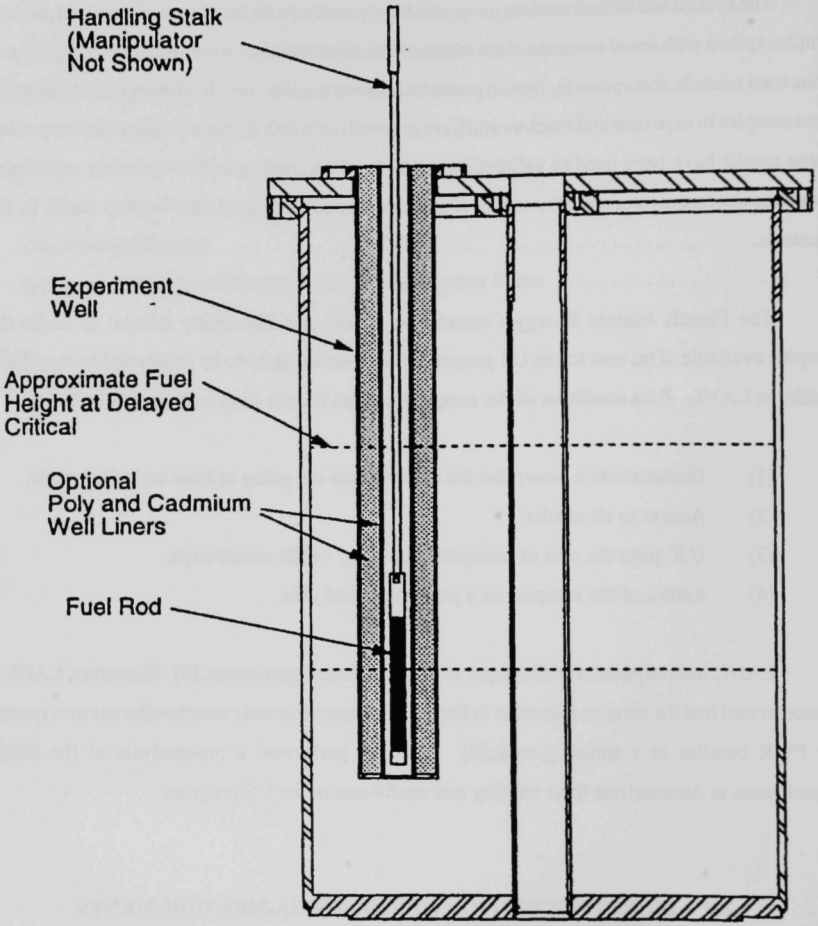

Fig. 1. Layout of Samples in SHEBA

well will be either unlined, or lined with polyethylene or polyethylene and cadmium (these three configurations will produce epithermal, thermal, and hard spectra) in the well. Spiked and reference samples will be introduced in the well and the relative worth will be inferred.

The experimental uncertainty is expected to be around 0.2 cents. The relative worths of the fission product spikes are expected to be comprised between 0 and 2 cents. Thus, it is possible that the measurements might be of very limited value for certain samples.

3.0 NEED FOR PRELIMINARY ANALYSIS

The original purpose of the CERES experiments was to validate in an integral sense the capture cross sections of the various fission products involved in the burnup credit analyses. The microscopic cross sections are usually known to within 20 to 30%. Thus great care was taken in the European experiments to reach experimental uncertainties below 10% (note that these uncertainties account for measurement uncertainties, but also for uncertainties in sample compositions and masses). While no precision criterion has yet been established for the SHEBA/CERES measurements, it is clear that a systematic measurement of all samples would constitute a potential waste of resources, and might also affect the credibility of the program.

4.0 ANALYSIS

The desired result of the calculational preanalysis was to verify that the difference in measured reactivity between each doped sample and the pure sample was within the capabilities of the experimental equipment used with SHEBA. The codes used to analyze the reactor were DRAGON[3] (collision probability lattice code), ONEDANT[4] (one-dimensional discrete ordinate), TWODANT[4] (two dimensional discrete ordinate), and MCNP[5] (continuous energy Monte Carlo). The use of the DRAGON code is in this case justified by the fact that it shares most of its algorithms with the lattice code APPOLLO-2[6], the basic tool used in France to analyze the CERES experimental results. The use of MCNP is motivated by the fact that it represents the reference

criticality safety Monte Carlo code of the Yucca Mountain Project. The two discrete ordinate codes were here used to evaluate axial effects (see details later). The multi-group codes were all setup to use the WIMS 69 group library with self-shielding effects calculated by the DRAGON code.

To determine the worth of the fission products, the reactivity change between the clean sample (no fission products) and the doped samples must be calculated. Calculation with MCNP were performed and the critical height (later used in the TWODANT calculations) was calculated. However, it was estimated that to evaluate reactivity effects introduced by the presence of the fission product samples with an accuracy comparable with that of the experimental uncertainty (of the order of 0.2 cents), several billions of histories had to be run, making this kind of calculations impractical at least on the ANL RA network. An unsuccessful attempt was made to use the perturbation option of the code. As a consequence, all the calculations presented in this paper were obtained using the multigroups codes.

The geometry for a horizontal slice through the SHEBA reactor was entered into the DRAGON code and the critical buckling with the pure sample inserted was found. The buckling of the doped sample was fixed to that of the clean sample, the fission product was added in, and the new k-effective of the system was found. The results of this calculation are provided in Table 1. The geometry used in the DRAGON accurately describes the off center position of the well, but neglects the axial effect due to the finite height (~10cm) of the sample. In order to quantify this effect the following procedure was used: first a corrective factor was calculated using a second model of DRAGON where the experimental well was put at the center, and then a second factor was calculated by comparing a ONEDANT calculation against the correspondent TWODANT calculation where the actual height of the sample was taken into account (S_{16} approximation was used it the discrete ordinate calculations). The reason for the evaluation of the first factor is related to the fact that both discrete ordinate codes cannot represent correctly the off center position of the experimental well. In any case this correction, as it can be seen in Table 1, is relatively small. In the same table the axial corrective factors are shown along with the final reactivity effects as calculated by this procedure.

Table 1. Calculational Results

Sample isotope content	2d DRAGON reactivities worths (cents)	Off center/center correction factors	Axial effect correction factors	Final corrected reactivity worths (cents)	Corrected reactivity worths (cents) with polyeth.
Ag-109	2.59	1.05	4.04	0.61	0.94
Cs-133	0.60	1.02	3.66	0.16	0.22
Eu-153	3.97	1.05	4.15	0.91	1.39
Gd-155	6.50	1.07	4.73	1.28	2.55
Rh-103	2.97	1.06	3.80	0.74	0.99
Sm-147	2.99	1.06	3.81	0.74	0.99
Sm-149	5.89	1.05	4.58	1.22	2.27
Sm-152	4.84	1.15	3.97	1.06	1.57
Nd-143	3.94	1.04	4.55	0.83	1.52
Nd-145	3.17	1.05	4.10	0.74	1.15
Tc-99	3.27	1.09	3.81	0.79	1.09

As shown, the final values are quite low and in the best case (Gd-155), the stated experimental uncertainty of ~0.2 cents[1] is already of the order of 15%, and reaches unacceptable values for samples of lower reactivity. Moreover the uncertainty for a reactivity variation has to be increased as the square root of the sum of the squares of the single experiment uncertainty (i.e., ~0.3 cents). In order to enhance the reactivity effects, the calculational procedure was rerun with the introduction in the experimental setup of the polyethylene sheath. The final results are shown in the last column of Table 1. In effect, the reactivity worths are increased by a factor between 1.5 and 2. Unfortunately this is obtained by a significantly softening in the spectrum. In Fig. 2 the spectra of the two SHEBA configurations (with and without) polyethylene are compared against that for a spent fuel rod in a shipping cask (this has been obtained from Ref. 2. The flux spectrum where the polyethylene is present cannot be considered representative of that of the spent fuel rod in the shipping cask.

More investigations have been performed in order to assess the representativity of the SHEBA spectrum. For this latter purpose the shipping cask fuel rod calculation was performed using the DRAGON code and the related 69 group library.

Figure 2. Comparison of Flux Spectra With and Without Polyethylene

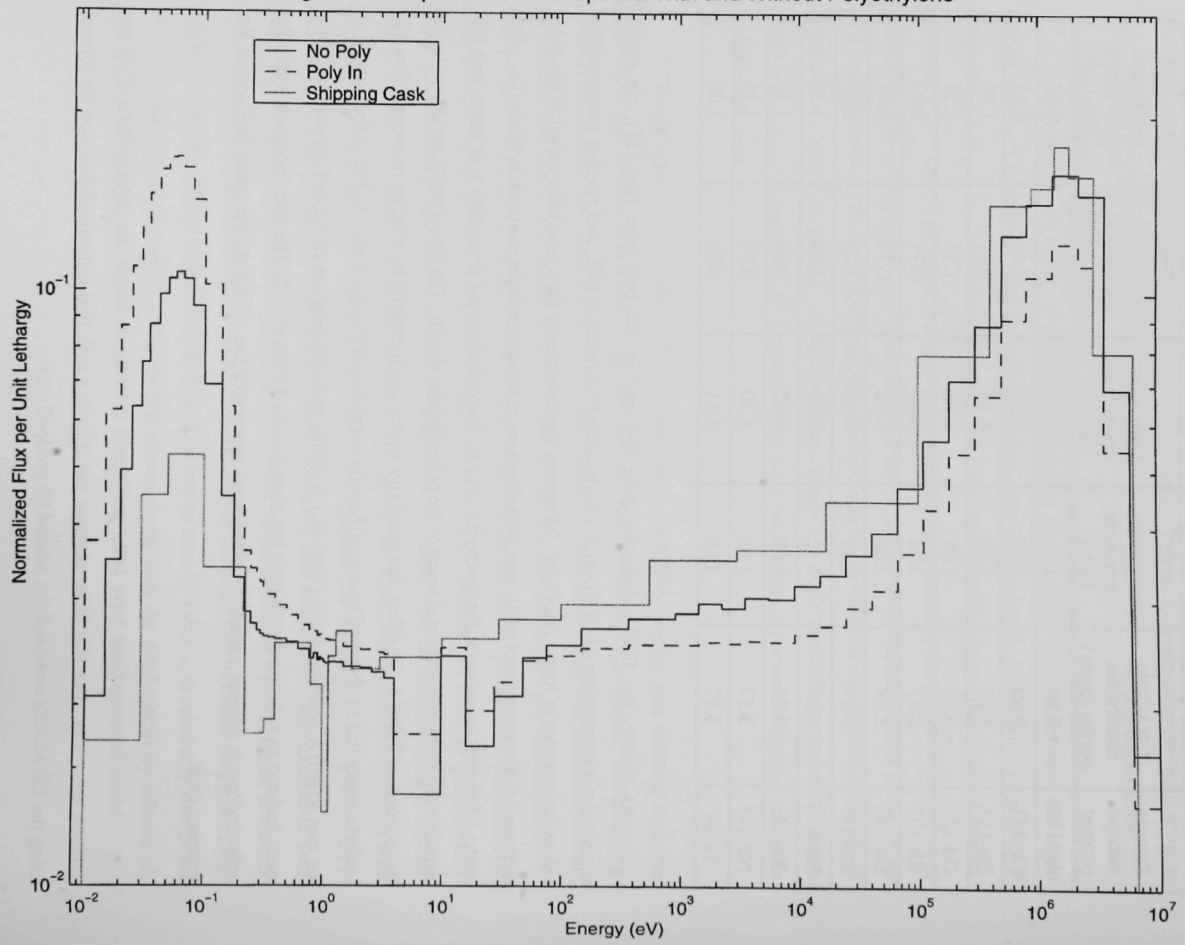

Figure 3 displays the normalized neutron spectra for a clean sample at the SHEBA sample irradiation position and for a shipping cask containing depleted PWR fuel at 50 MWD/T burnup. As can be seen, the SHEBA spectrum is softer than that of the shipping cask - the integrated SHEBA spectrum is ~20% higher than that of the cask over the thermal energy range below 0.3 eV, with a maximum of ~50% difference at 0.07 eV. The sharp dip in the cask spectrum at ~1.0 eV is due to the sharp Pu-240 absorption resonance at that energy, while the wider dip around ~0.3 eV is due to resonance absorptions in Pu-239 and AM-241.

Table 2 summarizes the results of neutron absorption rates for each individual fission product as calculated in SHEBA and in the shipping cask over three different energy ranges; a thermal range with upper energy cutoff at 0.625 eV, an epithermal energy range with neutron energies, E, between 0.625 eV < E < 9.119 keV, and a fast energy range with neutron energies, E > 9.119 keV. As expected, in all cases, thermal absorptions are over estimated by the softer SHEBA spectrum, whereas epithermal absorptions are underestimated. However, for the more important isotopes Gd-155, Sm-149, and Nd-143 (those producing the highest worth signals), the differences are minor because the thermal absorption component dominated.

5.0 EXPLOITATION OF EXPERIMENTAL RESULTS

In this section interpretation of the experimental measurements for use in supporting the Yucca Mountain spent fuel program is outlined.

First, let us summarize how the French program has conducted and exploited the CERES experimental analysis. The basic argument to justify the program was the validation of basic nuclear cross section data. CEA uses JEF 2.2 as their basic data files. APOLLO2 is the lattice code that generates self-shielded multigroup cross sections and can also perform Sn discrete ordinate calculations. The criticality safety community can also use a multigroup Monte Carlo code, MORET4, for more complex geometries. The cross sections used by MORET4 are those generated by APOLLO2. As we can see there is perfect consistency in the French approach; the same multigroup constants are used for criticality and deterministic reactor calculations. Any uncertainty,

Energy Dependence of Fission Products' Absorption Rates

FP	Absorption Rate (%)					
	E > 9.119 keV		9.119 KeV > E > 0.625 eV		0.625 eV > E	
	SHEBA	CASK	SHEBA	CASK	SHEBA	CASK
^{109}Ag	0.5	0.3	38.4	83.2	61.1	16.4
^{133}Cs	0.6	0.9	60.3	77.4	39.1	21.7
^{153}Eu	0.5	0.8	39.8	62.4	59.7	36.8
^{155}Gd	0.0	0.0	0.9	3.9	99.1	96.1
^{103}Rh	0.3	0.4	39.2	63.4	60.4	36.1
^{147}Sm	0.6	1.0	62.0	78.8	37.3	20.1
^{149}Sm	0.0	0.0	0.7	1.1	99.3	98.8
^{152}Sm	0.1	0.2	50.4	79.0	49.5	20.9
^{143}Nd	0.1	0.2	5.4	10.7	94.5	89.1
^{145}Nd	0.6	1.0	40.1	61.4	59.2	37.6
^{99}Tc	1.3	1.5	61.9	81.5	36.8	17.0
Background*	9.0	5.8	29.5	33.3	61.6	60.8

* Clean sample for SHEBA, and depleted fuel at 50 MWD/T burnup for the CASK.

Table 2. Energy Dependence of Fission Products' Absorption Rates

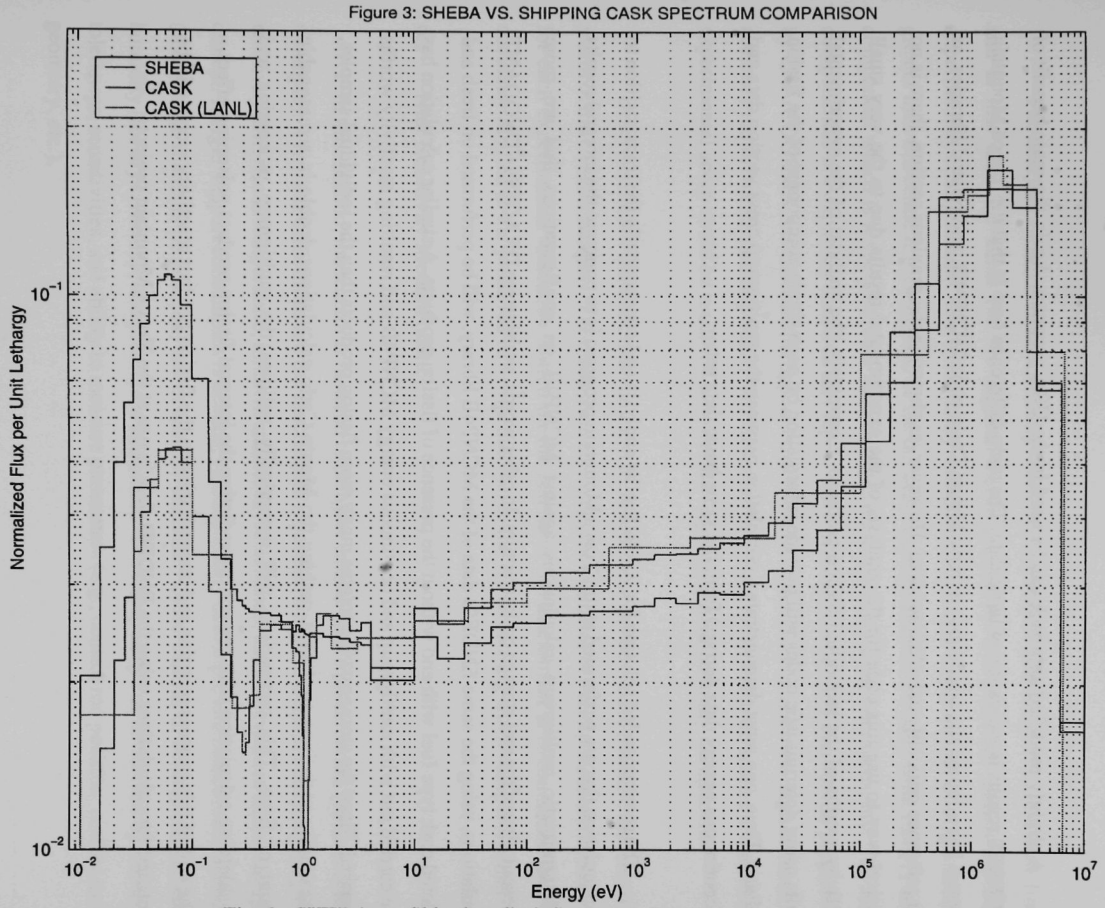

Fig. 3. SHEBA vs. Shipping Cask Spectrum Comparison

bias factor or cross section adjustment coming out from the analysis of the experiment is easily transposed to the design calculations because the same tools and cross section data are used.

A slightly modified approach can be used in the USA program. Again the main benefit of the CERES results is validation of basic data. The main difference here is that the Yucca Mountain program has adopted the continuous energy Monte Carlo code MCNP4B, and related libraries, as their reference criticality calculational tool. However, as shown in the previous section, there is no practical way to use this code for the analysis of the experimental results due to the very small reactivity worths of the individual fission products. Conversely, the analysis of the experimental results using deterministic codes will provide information on each single component of the fission products. Thus, one must demonstrate a correlation between the multigroup cross section data and the continuous energy data derived from the same basic data set.

The recommended solution for validating the analysis and consequently the transposition to the calculation that are performed at the Yucca Mountain program is to compare the integral results of deterministic multigroup calculations against MCNP4B on configurations that are more representative of the real storage cask structure. In other words, multigroup DRAGON+TWODANT calculations, using the same ENDF/B data of the MCNP4B library, will be performed on fresh and depleted cask type fuel with and without the presence of fission products. A similar calculation has to be carried out with multigroup and continuous energy MCNP4B and resulting reactivity worths compared. Since the storage cask contains many more fission products than the individual samples, the reactivity variations are larger, making the Monte Carlo calculations doable in a reasonable amount of time. This comparison will numerically validate the multigroup processing and self-shielding calculation with respect to predicting the integral fission product poisoning effect. At the end of this process margins and uncertainties on the fission product reactivity worth will be quantified for calculations using the ENDF/B data in use at the Yucca Mountain project.

6.0 POTENTIAL MODIFICATIONS TO THE EXPERIMENTAL SETUP TO REDUCE THE EXPERIMENTAL UNCERTAINTY

The analysis shows that the reactivity worth for the majority of samples is less than 1 cent and is less than 1.3 cents for the highest worth sample for the proposed SHEBA/CERES experimental configuration. The uncertainty associated with this experimental configuration is greater than 0.2 cents. It is comprised of the 0.2 cents experimental uncertainty from Ref [1] and a component which is associated with sample impurities, manufacturing tolerances, etc. The latter component is not explicitly stated in this report since this data is currently considered proprietary by CEA/COGEMA. At this time, it appears that the total uncertainty may be too high to meet the accuracy requirements of the sponsor, thus an assessment was performed to determine if the current experimental setup could be modified to lower the experimental uncertainty component.

Described below are some measurement techniques that can be used to measure the reactivity worth of the CERES samples. The discussion also includes estimates of the experimental sensitivity for each experimental technique. Based on the results of the assessment it is concluded that the oscillator method is the preferred experimental technique for measuring small sample worths.

6.1 Null Reactivity Method (static)

In this method, the reactor is restored to delayed critical after a perturbation (or insertion of a sample). Practical difficulties are the mechanical reproducibility (of control rods and samples), reactivity drift due to temperature, inherent statistical fluctuations, and achievement of true delayed critical. A rigid support for samples is needed, reproducibility of sample and control rod positions (and precise readouts of position) are of serious concern. Close control of reactor temperature, humidity (for dry criticals) , and pressure is important. The uncertainty can be derived by knowing tolerances, sensitivities, and ability to measure parameters (e.g., control rod position, reactor mass, geometry, etc.).

Conclusion: The uncertainty is completely dependent on the reactor system, but given the fact that this is a single measurement, it is difficult to achieve uncertainties of less than a few tenths of a cent. Dynamic methods are required to achieve better results.

6.2 Asymptotic Reactor Period Method

In this method, one looks at the asymptotic period. It requires precise knowledge of delayed neutron properties, and a small source term (the source term produces a non-asymptotic term to the kinetics). A step change in reactivity produces a superposition of exponentials, with the periods given by in-hour equation:

$$n(t) = \sum_{j=1}^{m+1} A_j e^{\omega_j t^i}$$

The solution of the roots is given by the in-hour equation,

$$\rho_0 = l\omega + \sum_i \frac{\beta_i \omega}{\omega + \lambda_i}$$

With six delayed groups (normally sufficient to describe the kinetics), there are seven roots. For positive reactivity, six are negative, and one is positive. The normal measurement of reactivity using the period waits until the negative contributions have died out. For a very small positive reactivity insertion, it can be shown that the asymptotic period is

$$\omega_l = \frac{\lambda}{\beta}\rho$$

For U-235, λ is approximately 0.07 and β is approximately 0.007, thus

$$\omega_l \approx 10\rho$$

For a 1 cent insertion, a reactor period of about 24 minutes would be obtained. The reactivity uncertainty in this type of measurement is dictated by the uncertainty in measurement of reactor period, and the existence of external sources in the reactor (With such a large period, the power increase will seem linear over a given time interval, but an external source will also cause a linear increase in power). Another serious problem is that of reactor drift over a long period of time, cause by temperature fluctuations for example. For this reason, reactor periods of longer than about 5 minutes are avoided (4 or 5 cents of reactivity).

When a comparison is made between two samples, differing by a very small amount of reactivity, the ratio of the two periods is simply the ratio of the reactivities. Consequently, the period between the two measurements will only differ by a small amount (equivalent to the percentage difference of the reactivity difference). Thus, accuracy in this method favors small reactor periods. Note that when comparing the reactivity difference between two samples, the same problems of sample placement occur as in the null reactivity method.

Conclusion: this method is not applicable to small (< 1 cent) reactivity measurements, even though the sensitivity of the stable period to reactivity is essentially linear in the limit of small reactivities.

6.3 Power History Measurements

This technique makes use of inverse kinetics to derive the reactivity following a perturbation. A reactivity perturbation will cause a change in power (increasing or decreasing). Note that the asymptotic period method described above is just a subset of this more general method, and with available electronics and computers, there is no reason not to use this more general method. The inverse kinetics equation is

$$\rho = \frac{l}{n}\frac{dn}{dt} + \frac{1}{n}\Sigma_i\left[\beta_i n(t_0) - l\lambda_i c_i(t_0)\right]e^{-\lambda_i(t-t_0)} + \frac{1}{n}\int_{t_0}^{t}\frac{dn(t')}{dt'}\sum_i \beta_i e^{-\lambda_i(t-t')}dt' - \frac{lq}{n}$$

Note that a source (q) appears in this equation as a false reactivity. In practice, a measure of the neutron population as a function of time allows this equation to be solved. Note that in the limit of a small reactivity step (after equilibrium has been achieved), this equation has an asymptotic solution of

$$\rho = \omega \frac{\beta}{l}$$

and properly gives the method of the previous section in that limit. The difference however, is that contributions to the reactivity are derived, essentially instantaneously, over a longer period of time. This has the effect of statistically making many measurements rather than waiting for an asymptotic period to be established with its problems of reactor drift. The effects of reactor drift and the source are easily seen in this measurement, and corrections can be applied. Note that if a sample is traversed into the core, and measurements are recorded continuously, a reactivity as a function of position is also obtained. This method has been shown to be accurate, and sensitivities of less than a tenth of a cent have been easily achieved.

Conclusion: This is an accurate method to determine reactivity after a perturbation and accuracies of less than a tenth of a cent are achievable.

6.4 Oscillator Measurements

Classically, the oscillator method has been utilized to determine the smallest sample worths. It has been shown that the limit of sensitivity available is dictated only by the reactor noise. In an epithermal reactor for example, small sample worths of 0.0001 cents have been routinely measured.[7] It essentially makes use of the inverse kinetics method of the previous section, but with an oscillating perturbation, many more `measurement' points are obtained. The reactor transfer function is simply related to the oscillating input reactivity as follows:

$$\frac{\Delta n(t)}{n} = \frac{\Delta k/k}{\omega\left[\left(\omega\sum_i \frac{\beta_i}{\omega^2+\lambda_i^2}\right)^2 + \left(1+\sum_i \frac{\beta_i\lambda_i}{\omega^2+\lambda_i^2}\right)^2\right]^{1/2}} \sin(\omega t - \phi)$$

Thus, the time behavior of the reactor power oscillates at the frequency of the reactivity, with a phase shift (which is a function of the neutron lifetime, delayed neutrons, etc.). For low frequencies (less than 1), the magnitude of this transfer function is insensitive to the neutron generation time. The accuracy of this method, especially in the case of comparing the relative worths of two different samples, derives from the fact that for a given frequency, the fluctuation in power is directly proportional to the fluctuation in reactivity. Physically, this is why the fundamental reactor noise is the limiting parameter to the accuracy.

The oscillator method as described here is an open loop, and the gain is inversely proportional to the frequency at low frequency. If there is reactor drift, it is likely to be at low frequency also, which can cause amplification of errors in the measurement. These errors can be minimized by operating the oscillator through a range of frequencies; fourier decomposition of the signals can eliminate low frequency drift effects.

An alternate method, shown to be just as accurate, is to operate the reactor as a closed loop system by controlling the reactor power during the sample oscillations with a calibrated control rod.[8] For sample worths on the order of a cent, the control rod holding power constant should have a total worth of perhaps 10 or 20 cents, and it should be operated in its middle (linear) range.

Conclusion: The oscillator method is the preferred experimental technique for measuring small sample worths. Sample worths of as little as 0.0001 cents have been measured with this technique. Measurements of 0.01 cents reactivity to 1% uncertainty are achievable.

7.0 OPERATIONAL AND SAFETY REQUIREMENTS TO PERFORM OSCILLATION MEASUREMENTS IN A REACTOR OR CRITICAL ASSEMBLY

To conduct these measurements in any given reactor requires several different tasks to be completed before any sample would ever be inserted. These tasks include physical modifications to the reactor facility, installation of the experimental equipment, and safety reviews and approvals. It is difficult to discuss these tasks in generic terms (not knowing the actual reactor configuration, or organization of the laboratory under which the approval to operate is provided) but a few of the key steps are highlighted in the sections below.

7.1 Physical Modifications to the Reactor

To conduct the experiment requires that there are two locations in the reactor - one to insert the samples and one to insert a low-worth control rod. Physical modifications may be required depending on the facility. Most reactors have at least one in-core location but not all have more than one. In addition, the reactor design must allow head space above the core or tank to allow two drive mechanisms to be located to control the sample and low-worth control rod. An ex-core location for an additional flux monitor is also necessary.

If the reactor does not have these capabilities, it usually requires a major modification to the facility. A major modification is defined as one in which the safety or integrity of the facility is affected, and does not necessarily refer to a difficult or costly modification. Although, because of the safety implications, the two are usually closely related.

A control system for the sample insertion, control rod, and flux monitoring is also necessary. This can be a significant effort based on the physical design of the experimental equipment and reactor type.

7.2 Installation of the Experimental Equipment and Conduct of the Experiment

Installation of the experimental equipment is necessary, however beyond the physical modifications to the reactor facility, this is fairly straight forward. Special procedures will be necessary if fuel movements or a reconfiguration of the core is required.

Conduct of the experiment will require special procedures unless the facility already has operating procedures that address the performance of experiments within the facility.

7.3 Safety Review and Approvals

Any experiment conducted in any facility must undergo a safety review to demonstrate that it is within the safety basis of the facility. This requires that a safety assessment be performed and documented, an Unreviewed Safety Question evaluation be performed and documented, and a NEPA assessment be conducted. The effort expended on these tasks is highly dependent on the facility and organization.

One tries to avoid the modification of the reactor facility, specifically systems important to safety, as any modification usually triggers an in-depth safety assessment and an Unreviewed Safety Question. That is, most modifications to the reactor are not within the scope of the current Safety Analysis Report and require an addendum or revision to the SAR. This task is usually daunting and requires a great deal of effort due to the level of revisions necessary and the depth of the review and approval. DOE must approve these types of revisions.

If a facility is chosen that can handle experiments and the introduction of samples and hardware into the reactor without a facility modification, the review and approval process is significantly reduced. An Unreviewed Safety Question may still arise depending on the flexibility of the facility in accommodating experiments. If a USQ is found to exist, then the same review process is necessary to approve the experiment. This is because the USQ indicates that the experiment is not within the safety basis. This could be the case, even if a facility modification is not necessary. For example, Even though an in-core irradiation position exists, the reactivity worth

of an experiment could be so large that it could affect the ability of the control system to safely shut down the reactor under postulated accident scenarios.

The best reactor candidate for the conduct of this experiment is a facility in which a reactor modification is not required and one in which the experiment does not involve a USQ and is within the safety basis of the existing Safety Analysis Report and Technical Specifications.

8.0 SUMMARY

The following points can be stated:

- The analysis shows that the reactivity worth for the majority of samples is less than 1 cent and is less than 1.3 cents for the highest worth sample for the proposed SHEBA/CERES experimental configuration. As expected, the reactivity worths increase when the spectrum is thermalized (e.g., use of polyethylene) nevertheless, the experiment becomes less representative of realistic cases. The measurements involving the use of cadmium is not recommended because the signal will be extremely small.

- The uncertainty associated with this experimental configuration is greater than 0.2 cents. It is comprised of the 0.2 cents experimental uncertainty from Ref [1] and a component which is associated with sample impurities, manufacturing tolerances, etc. CEA/COGEMA in Ref. 9 quotes that the total uncertainty for the CERES experiment measured reactivity variation can vary between 4% and 8%. Given the high relative uncertainties (<20%) associated with the SHEBA/CERES experiments it seems wise to consider also alternative experimental facilities for performing the measurement.

- The Yucca Mountain Project (YMP) needs to determine if the data from this proposed experiment is of sufficient accuracy to support their Disposal Criticality

Analysis Methodology Topical Report YMP/TR-004Q. Moreover, CEA/COGEMA will also need to determine that the data from the SHEBA/CERES experiments is of sufficient technical value to their criticality safety program. The latter point is one of the conditions imposed on the US by CEA/COGEMA before they approve the shipment of the CERES samples. It should be noted that the expected uncertainty/signal ratios will be significantly higher than in the European experimental program.

- It is also noted that the incorporation of an oscillation device into the experimental setup can significantly reduce the experimental uncertainty of the measurement. This was the same technique used by CEA in their experimental campaign. They have reported less than 10% **total** experimental uncertainties for their experimental data.

- The actions needed to install the oscillation device are also described (e.g., USQ, etc.). It is unclear to us that the oscillation device can be installed into SHEBA and that it will reduce the uncertainties sufficiently. This matter needs to be assessed.

- The experiment (with the oscillation device) could also be performed in a research reactor (e.g., TRIGA) which has an adequate neutron spectrum. However, it needs to demonstrated that the neutron spectrum in the alternative reactor is comparable to that expected in a flooded cask loaded with commercial spent nuclear fuel.

- Finally, any decisions regarding this experiment must meet the schedule of CEA/COGEMA since there is a limited time window.

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